

# Comment on cond-mat/0409228 "Microwave photoresponse in the 2D electron system caused by intra-Landau level transitions"

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We provide an article-extract which points out that a microwave-induced modification in the resistance occurs at relatively "high" magnetic fields where the radiation is incapable of producing inter-Landau level excitations and, therefore, that *the microwave radiation must be producing intra Landau level excitations as well.*

In the above mentioned cond-mat preprint entitled "Microwave photoresponse in the 2D electron system caused by intra-Landau level transitions", Dorozhkin et al.[1] have discussed a regime of the microwave-induced response in the 2DES that does not obtain much attention - the limit of "high" magnetic fields,  $B$ , where the Landau level spacing  $\hbar\omega_c$  exceeds the photon energy  $hf$ . Based on the available models for the microwave-induced magnetoresistance,[2] one naively expects little change in the magnetoresistance upon microwave excitation in this limit because inter Landau level excitations due to single photon processes are energetically unfavorable and unlikely when  $B > B_f$ , i.e.,  $\hbar\omega_c > hf$ . Here,  $B_f = 2\pi fm^*/e$ ,  $f$  is the microwave frequency,  $m^*$  is an effective mass, and  $e$  is the electron charge. Thus, this  $B > B_f$  regime is noteworthy because it points out further complexity in the experimentally observed phenomena, than what has been appreciated thus far.

In cond-mat/0409228,[1] the claim to novelty seems to be that the work represents the first conscious identification of a role for *intra Landau level transitions* in the microwave induced resistance response in the  $B > B_f$  limit.

An identification of a role for intra Landau level transitions in the microwave induced magnetoresistance in the  $B > B_f$  limit has been made previously, however, at the 13th International Winterschool on New Developments in Solid State Physics - Low Dimensional Systems, in Mauterndorf (Salzburg), Austria.[3] An extract from the associated paper, where the microwave induced magnetoresistance in the  $B > B_f$  limit has been attributed to spin-flip intra Landau level excitations, is provided in the following two pages.[3]

Perhaps, spin-flip intra Landau level excitations might constitute a viable mechanism for understanding the observed photo-induced magnetoresistance effect in the  $B > B_f$  limit.[3] Certainly, spin-flip intra Landau level excitations remain energetically plausible in the  $B > B_f$  limit, the spin splitting includes a  $B$  variation due to

the field induced Zeeman term, and, the magnitude of the spin-splitting, upon including spin-orbit effects, lies in the frequency (energy) range,[4] where the microwave radiation produces a resistance reduction.[3, 5]

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- [2] V. I. Ryzhii, Sov. Phys. - Sol. St. **11**, 2078 (1970); J. C. Phillips, Sol. St. Comm. **127**, 233 (2003); A. C. Durst et al., Phys. Rev. Lett. **91**, 086803 (2003); A. V. Andreev et al., Phys. Rev. Lett. **91**, 056803 (2003); J. Shi and X. C. Xie, Phys. Rev. Lett. **91**, 086801 (2003); F. S. Bergeret et al., Phys. Rev. B **67**, 241303 (2003); A. A. Koulakov and M. E. Raikh, Phys. Rev. B **68**, 115324 (2003); V. Ryzhii and R. Suris, J. Phys. Condens. Mat. **15**, 6855 (2003); X. L. Lei and S. Y. Liu, Phys. Rev. Lett. **91**, 226805 (2003); I. A. Dmitriev et al., Phys. Rev. Lett. **91**, 226802 (2003); cond-mat/0310668; V. Ryzhii and A. Satou, J. Phys. Soc. Jpn. **72**, 2718 (2003); M. G. Vavilov and I. L. Aleiner, Phys. Rev. B **69**, 035303 (2004); A. F. Volkov and V. V. Pavlovskii, Phys. Rev. B **69**, 125305 (2004).
- [3] R. G. Mani, in the Proceedings of the 13th International Winterschool on New Developments in Solid State Physics - Low Dimensional Systems, edited by G. Bauer, W. Jantsch, and F. Kuchar (Mauterndorf (Salzburg), Austria, 16-20 February, 2004) [Physica E (Amsterdam) (available online/29 July 2004)].
- [4] Y. A. Bychkov and E. I. Rashba, J Phys. C. **17**, 6039 (1984); G. Dresselhaus, Phys. Rev. **100**, 580 (1955); E. A. De Andrada e Silva et al., Phys. Rev. B **50**, 8523 (1994).
- [5] The argument has been made that spin-effects need not be considered here because "spin-splitting is not resolved." [1] Yet, it is not obvious that spin-splitting needs to be "resolved" for spin to have a perceptible effect on the radiation-induced magnetoresistance. Certainly, experiment has already shown a radiation-induced magnetoresistance effect (for  $B < B_f$ ) even where Landau level splitting is apparently "unresolved" by experiment, i.e., where SdH oscillations are not observable, see, for example, Fig. 3(a) in R. G. Mani et al., Phys. Rev. Lett. **92**, 146801 (2004).

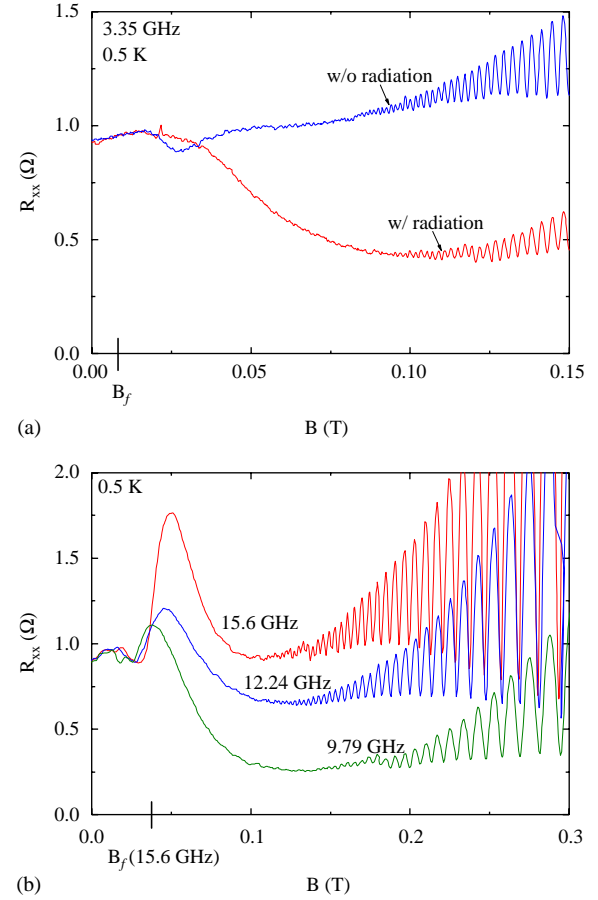


Fig. 3. This figure exhibits the effect of microwave irradiation on the diagonal resistance,  $R_{xx}$ , at relatively low microwave frequencies. (a) At  $f = 3.35$  GHz, the radiation mostly produces negative magnetoresistance at magnetic fields well above  $B_f$ , where the radiation seems incapable of producing inter-Landau level excitations. (b) With increasing  $f$ , the radiation-induced reduction in  $R_{xx}$  above  $B_f$  becomes less pronounced as a resistance maximum, the “first resistance maximum,” becomes perceptible.

illustrated by Figs. 3 and 4. At the lowest frequency,  $f = 3.35$  GHz, see Fig. 3(a), regular oscillations do not appear in  $R_{xx}$ , and the microwave radiation seems to produce mostly negative magnetoresistance, such that the irradiated  $R_{xx}$  falls below the dark  $R_{xx}$  at fields well above  $B_f$ . At fields above  $B_f$ , the radiation seems incapable of producing inter-Landau level excitations, and therefore, a new mechanism appears necessary to describe this low- $f$  behavior. As the radiation energy at the applied  $f$  in Fig. 3(a) seems

to lie in the vicinity of the expected zero-field spin splitting due to the Rashba and Dresselhaus terms in this GaAs/AlGaAs system [19], we suggest that the observed low  $f$  behavior might reflect radiation-induced mixing between spin levels of the same Landau band, and the modification of this mixing, due to the field-induced Zeeman term.

The effect of increasing  $f$ , at relatively low  $f$ , is exhibited in Fig. 3(b). Here, one observes that as  $f$

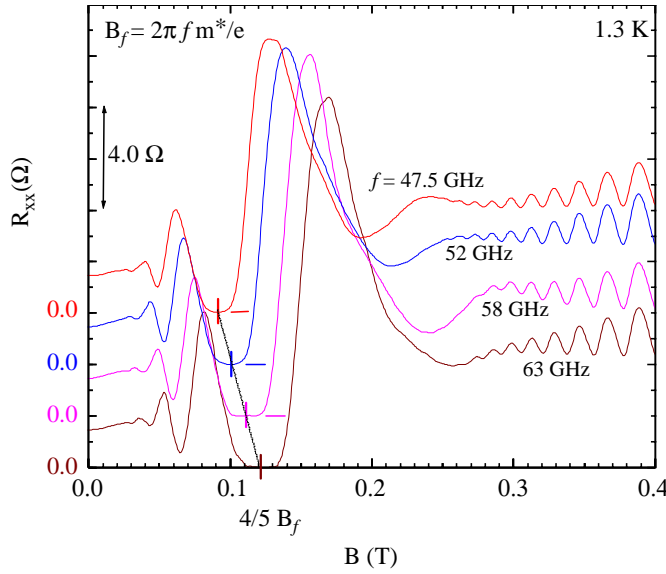


Fig. 4. This figure shows the development of the radiation induced zero-resistance states with the electromagnetic wave frequency,  $f$ , over an intermediate  $f$ -range, where a zero-resistance state occurs about  $\frac{4}{5} B_f$ . Note that the minima are shifted to progressively higher  $B$  with increasing  $f$ .

is increased from 9.79–15.6 GHz, the  $R_{xx}$  decrease below the dark  $R_{xx}$  becomes progressively weaker, as a peak in the  $R_{xx}$  develops with increasing  $f$ . Although a plurality of oscillations are not evident in  $R_{xx}$  at 15.6 GHz, it is clear that, at 15.6 GHz,  $B_f$  coincides with neither a minimum nor a maximum in  $R_{xx}$ , as in the higher  $f$  data to be exhibited in Fig. 4.

With a further increase in  $f$ , a number of radiation-induced oscillations become self-evident in  $R_{xx}$ , as shown in Fig. 4. Here, large amplitude oscillations that scale with  $f$  occur below 0.3 T, and these are attributed to the radiation-induced magneto-resistance effect, while the weak resistance oscillations between  $0.3 \leq B \leq 0.4$  T are associated with the Shubnikov–de Haas effect. The noteworthy feature here is the manifestation of a zero-resistance state about  $\frac{4}{5} B_f$ , which shifts to progressively higher  $B$ , with increasing  $f$ .